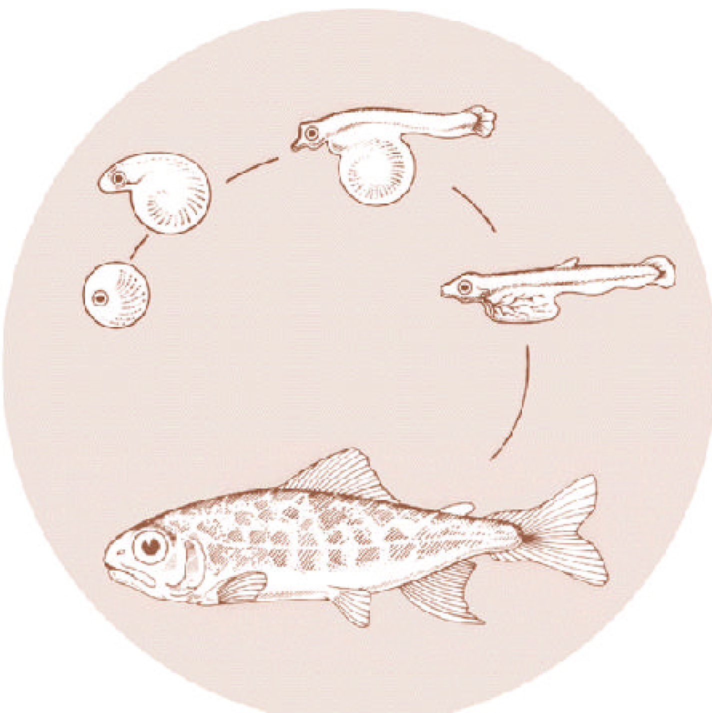
June 1994

PEN READING AND IMPRINTING OF FALL CHINOOK SALMON

Final Report



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PEN READING AND IMPRINTING
OF FALL CHINOOK SALMON

FINAL REPORT

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Abstract

Results of rearing upriver bright fall chinook salmon juveniles in net pens and a barrier net enclosure in two backwater areas and a pond along the Columbia River were compared with traditional hatchery methods. Growth, smoltification, and general condition of pen-reared fish receiving supplemental feeding were better than those of fish reared using traditional methods. Juvenile fish receiving no supplemental feeding were generally in poor condition resulting in a net loss of production. Rearing costs using pens were generally lower than in the hatchery. However, low adult returns resulted in greater cost per adult recovery than fish reared and released using traditional methods. Much of the differences in recovery rates may have been due to differences in rearing locations, as study sites were as much as 128 mi upstream from the hatcheries and study fish may have incurred higher mortality associated with downstream migration than control fish. Fish reared using these methods could be a cost-effective method of enhancing salmon production in the Columbia River Basin.

Introduction

The completion of John Day Dam (rm 216) in 1967 created a 76.4 mile long reservoir in the Columbia River, inundating salmon spawning and rearing habitat. To mitigate for this loss, upriver bright fall chinook salmon (*Oncorhvnchus tshawvtscha*) have been reared at Bonneville State Fish Hatchery (Oregon Department of Fish and Wildlife) and Spring Creek and Little White Salmon National Fish Hatcheries (NFH; U.S. Fish and Wildlife Service) for release above John Day Dam. In an effort to increase the return of adult salmon to this area, the U.S. Fish and Wildlife Service, with funding from the Bonneville Power Administration, began in 1983 to evaluate rearing and imprinting of juvenile fall chinook salmon in temporary facilities installed in backwaters and ponds adjacent to the Columbia River in John Day Reservoir. The goal of this project was to determine if upriver bright fall chinook salmon could be successfully reared and imprinted using temporary rearing facilities in backwaters along the Columbia River, resulting in adult contribution to various fisheries.

This is the final report of research conducted under this study. This report briefly summarizes rearing sites and treatments tested; describes adult returns from the various treatments, including those from Little White Salmon National Fish Hatchery (NFH); and compares costs of rearing fish and costs per adult recovery using the different methods. More detailed information from individual years of this study can be found in Novotny et al. (1984, 1985a, 1985b, 1987), Beeman and Novotny (1990), and Novotny and Macy (1989, 1991).

Methods

Thirty-four potential backwater areas were surveyed and rated in 1983 according to their suitability for rearing juvenile salmon. Two sites, Social Security Pond (rm 290), and the backwater at Rock Creek (rm 228) were selected for this study based on criteria including depth, area, accessibility, potential for water temperature fluctuations and wave action, entrance to the Columbia River, public use, and water quality (Novotny et al. 1984). A third site, Drano Lake (rm 162), was selected in 1987 (Novotny et al. 1987; Figure 1).

Fish used for this study were "upriver bright" fall chinook salmon from adults spawned at Bonneville State Fish Hatchery and hatched and initially reared at Spring Creek or Little White Salmon NFH. Fish reared at the off-station sites from 1984-1986 were from Spring Creek NFH. Fish reared in 1987 were from the Little White Salmon NFH, as the upriver bright fall chinook

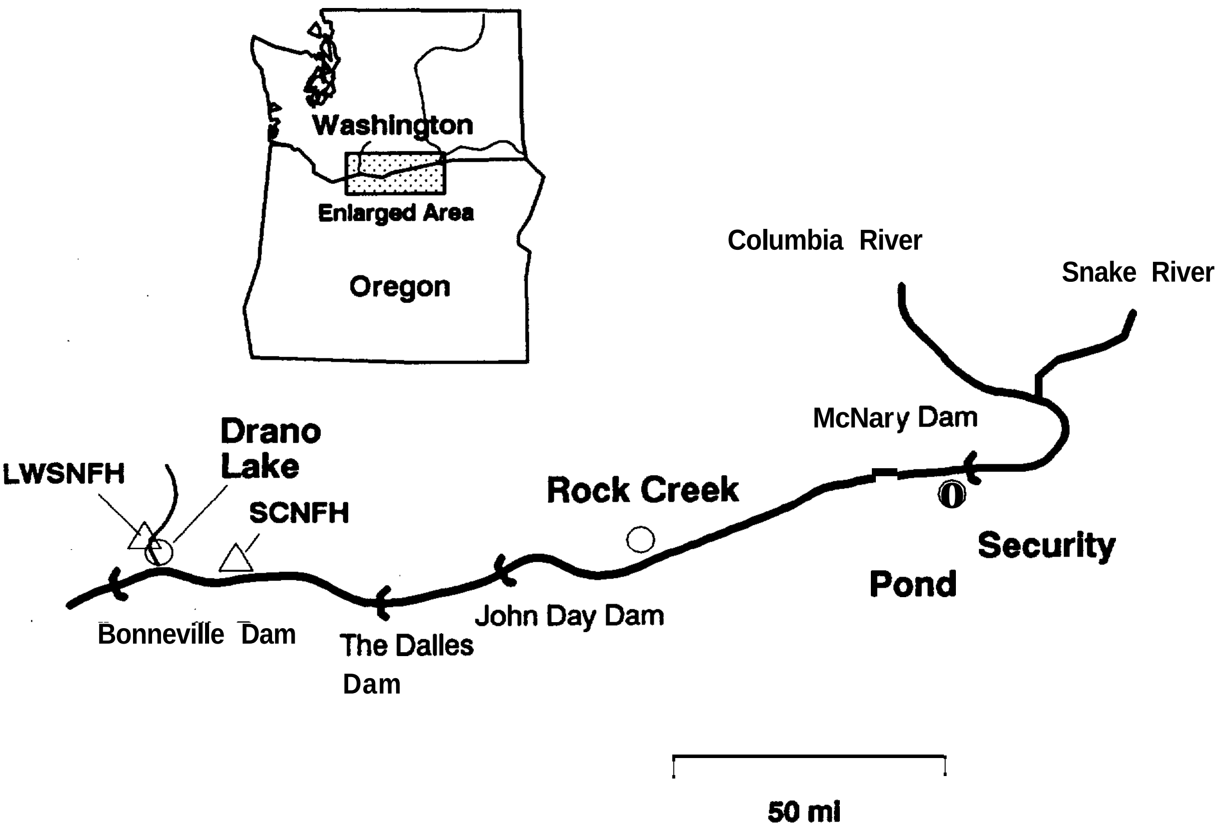

Figure 1. Map of off-station rearing sites (0) and fish hatcheries (A) where upriver bright fall chinook salmon were reared prior to transfer to the off-station sites. LWSNFH = Little White Salmon NFH, SCNFH = Spring Creek NFH.

program was transferred from Spring Creek NFH to Little White Salmon NFH after 1986. Fish reared and released from the Little White Salmon NFH were used as controls in each year, since upriver bright fish were not released directly from Spring Creek NFH. All fish except those reared in pens without supplemental feeding (see below) were coded-wire-tagged and adipose-fin-clipped for evaluation of adult recoveries.

The rearing phase of this project began with density and feeding-ration trials in 1984 and continued at Rock Creek and Social Security Pond through 1986. Initial rearing densities were conservatively calculated based on minimal flows, suitable water quality, maximum rearing temperatures of 61 F, and release weights of 45 fish/lb (Novotny et al. 1984). Carrying capacity estimates given these parameters were from Leitritz and Lewis (1980).

The primary rearing enclosures used were 20 ft X 20 ft X 7 ft net pens enclosing an area of 2800 ft^3; pens were fitted with nets with a 0.2 in mesh. Fish were typically transferred from the hatcheries in March and released from the study sites from mid-May to early June. The fish were reared until they had reached a size of about 90/lb (5.0 g), or until water temperatures reached and remained above 60 F, as disease problems' were noted above this temperature during 1984 rearing trials. Fish in pens were reared with and without supplemental feeding to determine if the natural food base would be sufficient for fish growth.

Rearing treatments tested during this study are summarized in Table 1. Fish in the fed treatments were fed Abernathy Dry at a rate of 3-4% body weight/day. These fish were reared at four densities (regular, double, triple, quadruple), ranging from 0.016 lb/ft^3 to 0.084 lb/ft^3; about 18000 to 75000 fish per pen. The treatments greater than the regular density were added to the study design as the study progressed in an attempt to address questions concerning maximum possible rearing densities at the study sites. Fish in the unfed treatments were reared at three densities, ranging from 0.001 lb/ft^3 to 0.004 lb/ft^3; about 1000 to 4000 fish per pen. More detailed information pertaining to rearing can be found in Novotny et al. (1984, 1985a, 1985b, 1986, 1987) and Novotny and Macy (1991).

A barrier net enclosure was tested at Rock Creek during 1985 and 1986 (Novotny and Macy 1989; Table 1). The net extended 200 ft out from the shoreline on both sides and 300 ft across on the outside, enclosing an area of 1.48 acre (about 671,000 ft^3 at minimum pool). Fish in the barrier net were reared without supplemental feeding at 0.001 lb/ft^3; about 250,000 fish at stocking.

During rearing, the growth, mortality, and physiology of

Table 1. Summary of treatments tested at Rock Creek (RC), Social Security Pond (SSP), and Drano Lake (DL) upriver bright fall chinook salmon off-station rearing sites in 1984-1987. Rearing enclosures included net pens (Pen) and a barrier net (Bnet).

Year	Site	Enclosure Type	Treat-ment	Stocked #/pen	Stocked #/lb	Stocked lb/ft^3	Released #/lb	Released lb/ft^3	Production lb/ft^3
				Fed Treatments					
1984	SSP	Pen	Various[a]	6567-17330	225	O.OlO-0.027	64-75	0.030-0.076	O.019-0.050
	RC	Pen	Various[a]	**8198-17718**	225	D.013-0.028	48-77	0.042-0.083	0.029-0.055
1985	SSP	Pen	Regular	18750	323	0.021	106	0.062	0.041
	RC	Pen	Regular	**19738**	323	0.023	118	0.061	0.038
1986	SSP	Pen	Regular	**18636**	227	0.030	90	0.073	0.043
	RC	Pen	Regular	**18328**	227	0.029	78	0.081	0.052
			Double	38005	284	. 0.048	70	0.193	0.145
			Triple	55183	284	0.069	72	0.272	0.203
1987	OL	Pen	Regular	18341	413	0.016	107	0.060	0.044
			Double	37206	413	0.032	**101**	0.130	0.098
			Triple	55130	430	0.048	**110**	0.176	0.128
			Quadruple	75202	504	0.053	**105**	0.253	0.200
				Unfed Treatments					
1984	RC	Pen	Low	518	160	**0.001**	66	0.002	**0.001**
		Bnet	---	**79442**	**160**	**0.001**	82	**0.001**	**0**
1985	RC	Pen	Low	1036	186	0.002	122	0.002	**0**
			Medium	2036	186	0.004	**139**	0.004	**0**
			High	4249	186	0.008	**157**	0.007	**- 0.001**
		Bnet	---	**254194**	304	0.001	**169**	0.001	**0**
1986	RC	Pen	Low	968	**197**	0.002	**152**	0.009	0.007
			Medium	1653	**197**	0.003	**172**	**0.011**	0.008
			High	3702	**197**	0.007	224	**0.014**	0.007
		Bnet	---	**219466**	284	**0.001**	232	0.002	0.001
1987	DL	Pen	Low	991	450	**0.001**	395	**0.001**	**0**
			Medium	1982	450	0.002	560	**0.001**	- **0.001**
			High	3964	450	0.003	568	0.002	**- 0.001**

a Several density and feeding rations were tested in 1984 prior to production rearing in subsequent years.

fish reared off-station were compared with those reared at Spring Creek NFH (1984-1986) or Little White Salmon NFH (1987). Changes in fork length, weight, smoltification, and general condition were measured at regular intervals. Smoltification was assessed by measuring gill Na+,K+-ATPase (ATPase) activity using the method of Zaugg (1982). General fish condition was assessed using a fish health condition profile (Goede 1988).

Prior to the 1987 rearing trials, brood stock spawned at Little White Salmon NFH were diagnosed with Infectious Hematopoietic Necroses (IHN). Eggs from the entire upriver bright stock at the hatchery were subsequently exposed to IHN virus in the rearing water at the hatchery. Therefore, transferring fish to the off-station rearing sites was not possible since it was contrary to disease policies of the U.S. Fish and Wildlife Service and other agencies in the Columbia Basin. To continue the study, net pens from Rock Creek were relocated to Drano Lake, the backwater of the Little White Salmon River adjacent to the hatchery (Figure 1). After the juvenile fish were transferred to the net pens in Drano Lake, those in the hatchery were diagnosed with IHN; these fish were destroyed. Over the course of rearing, fish in the net pens were examined for the presence of disease on eight occasions during the 10-week period between fish marking and release. Results of each examination was negative and the fish were released on schedule. Fish were not reared at Rock Creek or Social Security Pond in 1987.

Adult returns of fish reared off-station were compared with those reared and released from the Little White Salmon NFH, as all upriver bright chinook salmon reared at Spring Creek NFH were released at off-station locations. Fish reared at the Little White Salmon NFH were released directly from the hatchery into Bonneville Reservoir, 2 dams and reservoirs downstream from the release sites of the study fish.

A combination of trap nets and weirs was used to capture adults returning to the rearing sites during 1985-1989. A Merwin trap-net was the most effective means of capturing returning adults at Rock Creek. Due to the lack of adult recaptures at Social Security Pond, adult recovery efforts were abandoned at this site after 1986. The fish ladder at the Little White Salmon NFH was used to capture on-site returns from the 1987 rearing trials in Drano Lake.

Adult recoveries were compiled from coded-wire-tag information in the Pacific States Marine Fisheries Commission (PSMFC) Regional Mark Information System database (PSMFC, Portland, OR). Recoveries presented in this report were those listed in the database as of June, 1993. Recoveries were divided into on-site (actual numbers of fish recovered at the rearing sites), ocean (estimated numbers of fish recovered in the Pacific

Ocean), and in-river (estimated numbers of fish recovered in the Columbia and Snake rivers including recoveries in sport, commercial, and treaty fisheries, hatcheries other than the Little White Salmon NFH, and counts from spawning ground surveys).

Differences in total percent adult recoveries were tested for significance using parametric statistics after data transformation. To normalize the percent recovery data, a modification of the Freeman and Tukey arcsine transformation was used (Zar 1984). This equation is

$$p' = 0.5 * \arcsin\sqrt{\frac{X}{n+1}} + \arcsin\sqrt{\frac{x+1}{n+1}}$$

where X = the number of adults recovered and n = the number of fish released. Differences between arcsin-transformed percent adult recoveries (recoveries) of the fish reared in net pen, hatchery, and barrier net treatments were tested for significance using analysis of variance using a general linear models (GLM) procedure followed by Student-Newman-Keuls multiple-range tests when GLM indicated significant differences existed (SAS Institute 1986). Differences were considered significant when $P \leq 0.05$. Comparisons between treatments in 1984 were not made because there was only 1 tag code per site in this year. In addition, comparisons between net pen and hatchery treatments were not possible for the 1987 rearing year as the upriver bright chinook salmon at Little White Salmon NFH were destroyed due to disease.

Rearing costs were compared using Present Value Theory (Senn et al. 1984). This method incorporates capital costs, project life, and operating costs of each method, enabling comparisons of diverse methods on a common scale. In our estimates, "hatchery efficiency ratios" (HER), in dollars per pound produced, were calculated based on the costs to produce a net gain of 1000 lb of fish using each method. Rearing costs were based on actual rearing expenses whenever possible, although some cost estimates for hatchery rearing were from Senn et al. (1984).

Estimates of rearing cost per adult recovery were made for each treatment based on the HER, the size at release (number per pound), the number of fish released, and the total number of adults recovered in all fisheries. The dollar amount per adult recovery was calculated as: (HER ÷ size at release X number of fish released ÷ number of adults recovered). To permit comparisons between off-station rearing and hatchery rearing, these estimates included only costs associated with rearing at the hatchery during the time fish were reared off-station.

Results

The off-station rearing areas were characterized by higher water temperatures during the rearing periods (early March to June) than at Spring Creek NFH or Little White Salmon NFH. Surface water temperatures at the time of fish stocking were typically above 50 F at Rock Creek and Social Security Pond and were about 45 F at Drano Lake, increasing throughout the rearing period to over 54 F at Drano Lake and over 59 F at the other sites (Novotny at al. 1984, 1985a, 1985b, 1987; Beeman and Novotny 1990). Water temperatures during rearing were relatively stable at the hatcheries, ranging from 50-52 F and 43-46 F at Spring Creek NFH and Little White Salmon NFH, respectively.

Fed fish in pens grew faster than fish reared at Spring Creek NFH or Little White Salmon NFH. Instantaneous growth rates and mean sizes at release were similar between all density treatments of fed fish in pens at Rock Creek in 1986 and at Drano Lake in 1987 (Novotny at al. 1985b, 1987; Beeman and Novotny 1990). Fish reared without supplemental feeding in pens and the barrier net grew poorly, if at all, and a net loss of production during the rearing period was observed on several occasions (Table 1).

Smoltification, as indicated by elevated gill ATPase activities, was more pronounced in fed fish reared off-station than in fish reared at Spring Creek NFH. Mean gill ATPase activities of fish reared and released from the hatcheries were relatively constant, fluctuating from about 8 μmoles P_i mg protein^{-1} h^{-1} (units) to about 10 units (Novotny at al. 1984, 1985a, 1985b, 1987; Beeman and Novotny 1990). Mean gill ATPase activities of fish reared in regular density fed treatments at the off-station sites typically increased'from about 10 units at the time of transfer from the hatchery to the sites, to about 30-35 units prior to release; increases were typically initiated in early May. Smoltification of fish reared at the increased densities tested in 1986 and 1987 was similar to that in the regular density treatments. Development of smoltification in fish reared without supplemental feeding was generally less than that observed from fish in the fed treatments and at Spring Creek NFH.

General fish condition did not depart from what was considered normal in any fish examined from the off-station fed treatments or Spring Creek NFH. Fed fish reared at the off-station sites generally had higher mean fats and condition factors than fish reared at Spring Creek NFH, whereas unfed fish had very low mean fats and condition factors (Novotny and Beeman 1990).

Recoveries of fish released from the regular density treatments in pens in 1985 and 1986 were significantly lower than those released at the Little White Salmon NFH (Table 2; Figure 2; Appendices 1, 2). Recoveries from regular density treatments at Social Security Pond were significantly higher than those from Rock Creek in 1986, but there was no difference in recovery from these sites in 1985. Recoveries from all sites were significantly higher in 1985 than in 1986.

On-site, ocean, and in-river recoveries of fish reared and released from the regular density pens were significantly lower than those of fish reared in the hatchery. The only exception was the in-river recovery in 1986, in which there was no difference between fish reared at Social Security Pond and the hatchery. The largest differences were in the on-site recoveries. The on-site recoveries of treatments at Rock Creek ranged from less than 0.001% to 0.014%, compared to a range of 0.067% to 0.207% for the hatchery. No adults were recovered at Social Security Pond, although efforts to recover adults were not made at this site after 1986 due to the absence of recoveries in 1985 and 1986.

There were few significant differences in recoveries among the various density treatments of fed fish in net pens (Figure 3A). Recoveries from the regular density treatment at Rock Creek in 1986 were significantly higher than those from the double density treatment, but the triple density treatment was not significantly different from either of these. In addition, the regular density treatment at Rock Creek also resulted in a significantly higher in-river recovery than the triple density, which was higher than the double density treatment. There were no significant differences in the recoveries in the other fisheries. Recoveries from the regular density treatment at Rock Creek were significantly higher than those from the barrier net treatment at this site in both 1985 and 1986. There were no significant differences in recoveries among the four densities used at Drano Lake in 1987.

There was a direct relation between the number of fish reared in the pens and the total number of adult recoveries per pen. This relation was most evident in the 1987 Drano Lake trials, in which each increase in density produced a significant increase in the total number of adults recovered per pen (Figure 3B). The triple density treatment at Rock Creek in 1986 resulted in significantly more adult recoveries per pen than the regular and double densities, which were not different from each other.

Hatchery efficiency ratios varied widely among treatments (Table 3). The HER for the hatchery treatment was $5.10 and was assumed to be equal in each year. The HERs from the fed pen treatments ranged from $2.23 for quadruple density treatments to $9.90 for regular density treatments. The barrier net HER was $29.06 1986. No HER was calculated for the 1985 barrier net

Table 2. Adult recovery summaries (expanded number and percent) of upriver bright fall chinook salmon reared and released at Rock Creek (RC), Social Security Pond(SSP), and the Little White Salmon NFH (LW), including totals for each area of recovery (on-site, ocean, or in-river). Treatments include regular (Reg), double (Dbl), triple (Trp) and quadruple (Qua) densities in net pens, barrier net (bnt), and hatchery raceway (rwy). tr = less than 0.001%.

Year	Site	Treat-ment	Number Released	On-site No.	On-site %	Ocean No.	Ocean %	In-river No.	In-river %	Total No.	Total %
1984	SSP	Reg	72027	0	0	55	0.076	115	0.160	170	0.236
	RC	Reg	79610	11	0.014	176	0.221	228	0.286	415	0.521
	LW	Reg	94847	109	0.115	360	0.380	430	0.453	899	0.948
1985	SSP	Reg	204575	0	0	492	0.240	1086	0.531	1578	0.771
	RC	Reg	196064	9	0.004	457	0.233	904	0.461	1370	0.699
	RC	Bnt	122526	16	0.013	149	0.122	400	0.326	565	0.461
	LW	RWY	186061	386	0.207	1509	0.811	1778	0.956	3673	1.974
1986	SSP	Reg	210771	0	0	186	0.088	377	0.179	563	0.267
	RC	Reg	205930	1	tr	147	0.071	222	0.108	370	0.180
	RC	Dbl	70803	0	0	31	0.044	26	0.037		0.080
	RC	Trp	105839	2	0.002	56	0.053	73	0.069	15:	0.124
	RC	Bnt	207680	0		13	0.006	75	0.036	88	0.042
	LW	RWY	195310	131	0.06;	285	0.146	381	0.195	797	0.408
1987	DL	Reg	194917	202	0.104	468	0.240	465	0.238	1135	0.582
	DL	Dbl	65880	64	0.097	130	0.197	132	0.200	326	0.495
	DL	Trp	98005	77	0.078	173	0.176	202	0.206	462	0.471
	DL	Qua	121839	118	0.097	301	0.247	218	0.179	637	0.523

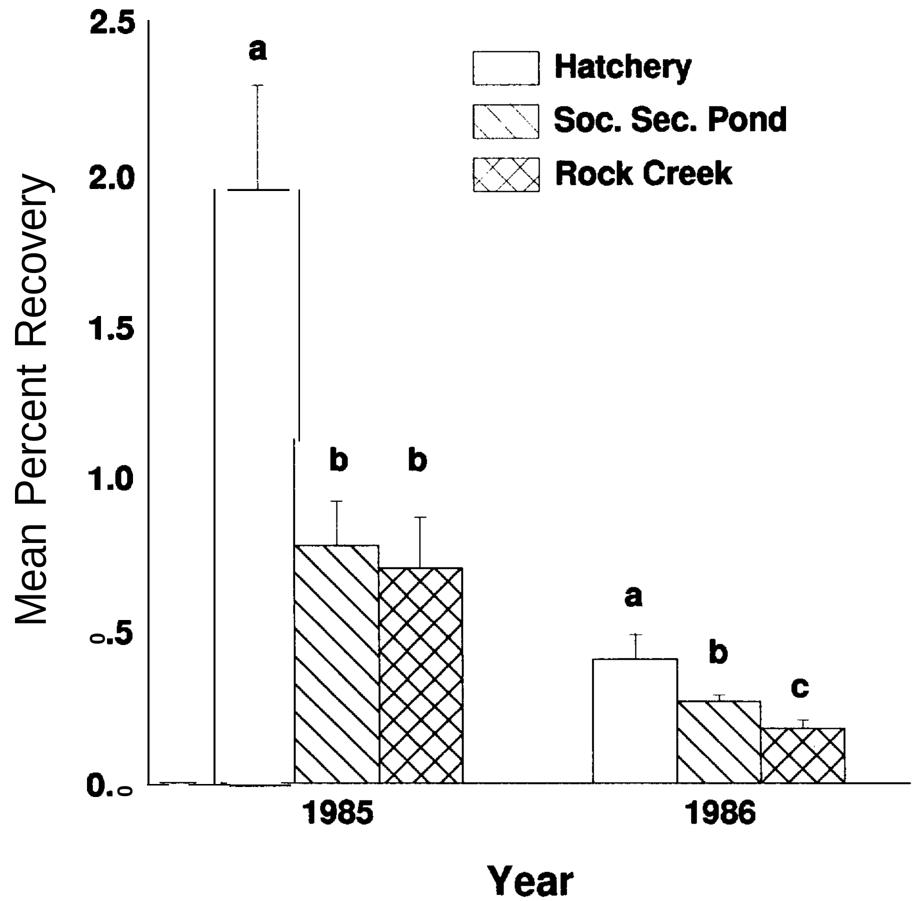

Figure 2. Mean percent adult recoveries in all fisheries for upriver bright fall chinook salmon reared and released from the Little White Salmon NFH (Hatchery), and fish fed a full hatchery ration reared in the regular density net pen treatments at Rock Creek and Social Security Pond (Soc. Sec. Pond) during 1985 and 1986. Vertical bars represent one standard deviation. Bars with the same letter are not significantly different from one another in the same year ($P \leq 0.05$).

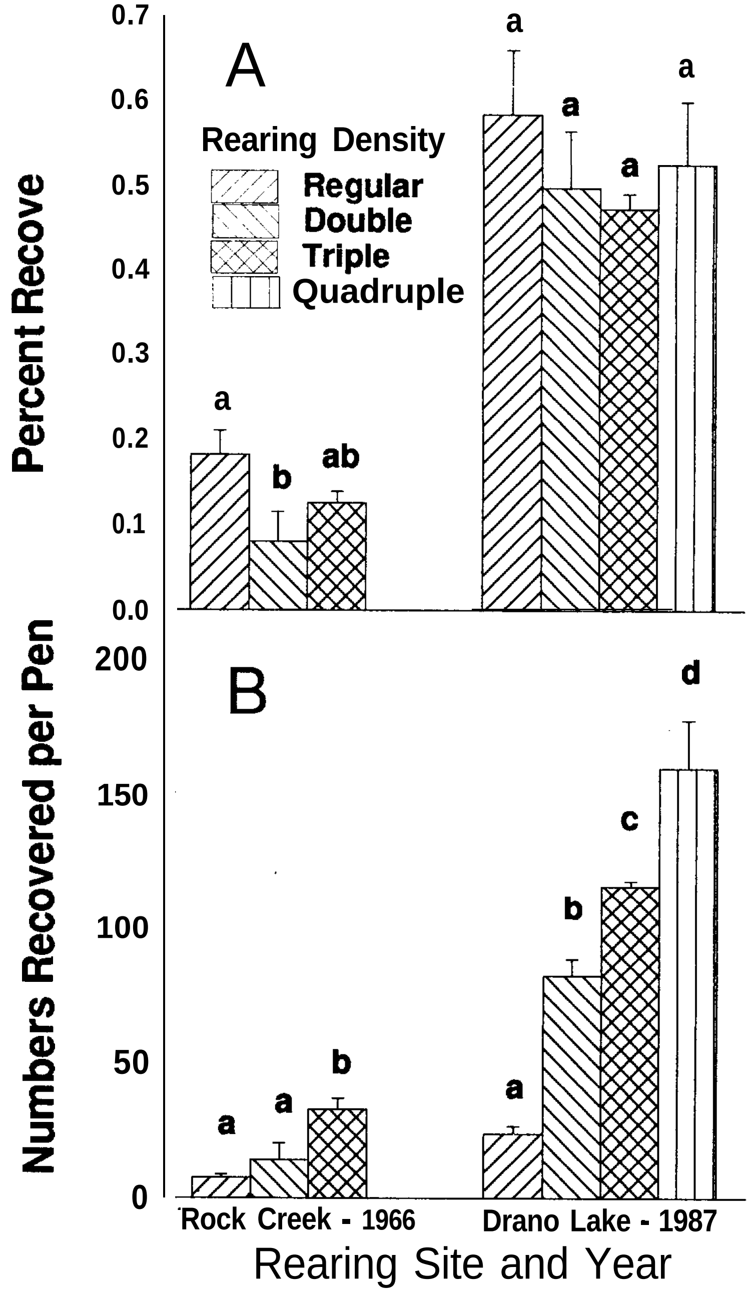

Figure 3. Mean total percent (A) and mean numbers (B) of total adult upriver bright fall chinook salmon recoveries per net pen for several densities of fed fish reared in net pens at Rock Creek in 1986 and Drano Lake in 1987. Vertical bars represent one standard deviation. Bars with the same letter are not significantly different from one another in the same site and year ($P \leq 0.05$).

Table 3. Costs used to calculate hatchery efficiency ratios (HER; Senn et al. 1984) based on actual costs incurred rearing upriver bright fall chinook salmon in net pens at different rearing treatments and within a barrier net during 1985-1987. Hatchery costs are based on costs in Senn et al. (1984). Costs are expressed as those required to produce a net gain of 1000 lb of fish using each method. SSP = Social Security Pond, RC = Rock Creek, DL = Drano Lake, LW = Little White Salmon NFH. Bnet = barrier net, Reg = regular, Dbl = double, Trp = triple, and Qua = quadruple density treatments.

Year	Treatment	No. units	Pens, raceways'	Feed-ers	Nets, covers	Food[b]	O&M[c]	Labor[d]	HER (S/lb)
1985	SSP Reg	8.7	17522	3610	5002	490	2614	2610	9.28
	RC Reg	9.2	18529	3818	5290	640	2764	2760	9.90
	LW	n/a	6440	6000[e]	0[f]	600	2350	835	5.10
1986	SSP Reg	8.1	16313	3362	4658	548	2434	2430	8.76
	RC Reg	6.7	13494	2780	3852	526	2012	2010	7.64
	RC Dbl	2.6	5236	1079	1495	422	780	780	3.09
	RC Trp	1.9	3827	788	1092	400	570	570	2.34
	BNET	6.0	110634	0	0	0	11063	0	29.06
	LW	n/a	6440	6000[e]	0[f]	600	2350	835	5.10
1987	DL Reg	8.1	16313	3362	4658	393	2434	2430	8.61
	DL Dbl	3.6	7250	1494	2070	333	1082	1080	3.96
	DL Trp	2.8	5639	1162	1610	356	840	840	3.15
	DL Qua	1.8	3625	747	1035	410	540	540	2.23

a Based on life expectancies of 20 yr for pen frames, feeders, and floats; 7 yr for nets; 50 yr for hatchery raceways (Senn at al. 1984)

b Food costs based on the use of Oregon Moist Pellet at $0.60/lb for hatchery and Abernathy Dry at $0.45/lb for all other treatments.

c O&M expense based on 10% of capital investment/yr for net pens and barrier net, and $2.35/1b produced for the hatchery (personal communication, J. Bodle, Little White Salmon NFH manager).

d Labor costs based on an annual salary of $25,000 and 0.012 man-year/pen and 0.033 man-year/lb produced at the hatchery.

e Represents hatchery plumbing costs, assuming a life expectancy of 25 yr.

f Represents water costs at Little White Salmon NFH. They are zero due to water rights on Little White Salmon River.

trial because there was no net gain in production during this year. Higher densities lowered rearing costs, and this was reflected in the lower HERs of these treatments in 1986 and 1987.

Based on cost per adult recovered, the hatchery raceway was a more economical rearing method than the net pen or barrier net treatments. Rearing cost per adult recovered for the hatchery was $2.97 in 1985 and $11.57 in 1986 (Table 4). The cost per adult recovered from the fed pen treatments ranged from an low of $4.06 for the quadruple density (Drano Lake, 1987) to $54.83 for the double density (Rock Creek, 1986). The barrier net treatment in 1986 was the least economical method, resulting in a rearing cost of $295.61 per adult recovered. These numbers depended primarily on the number of adults recovered in each year, as the rearing costs varied little between years. Barrier net costs per recovery were also inflated by a high HER. Rearing costs per adult recovered were reduced at the higher densities used in 1986 and 1987.

Discussion

Fish were successfully reared at the off-station sites, resulting in adult contributions to various fisheries, but on-site recoveries were low. However, on-site recoveries may have been underestimated due to ineffective recapture methods at some sites. For example, no on-site recoveries were made at Social Security Pond in any year, but there were substantial in-river recoveries in the area of this site.

Rearing fish in the hatchery resulted in higher recoveries and lower rearing costs per adult recovered (all fisheries combined) than any of the other methods tested. Despite lower actual rearing costs in some off-station treatments, low adult recoveries made these methods less economical than the hatchery method.

Much, if not all, of the reason for the lower recoveries from the off-station sites compared to those from the Little White Salmon NFH can probably be attributed to the differences in rearing locations. Juveniles reared at the two upstream rearing sites were required to migrate past two dams and many miles of reservoir (Social Security Pond, 128 mi; Rock Creek, 66 mi) before reaching the downstream release site of the hatchery-reared controls.

Estimates of juvenile mortality associated with dam and reservoir passage vary from 10% to 45% per project (Schoeneman 1961; Sims and Ossiander 1981; McKenzie et al. 1983). This includes mortality from predation by other fishes, which has been estimated as 14% in John Day Reservoir alone (Rieman et al.

Table 4. Data used to calculate cost per adult fish returned. Dollars per recovery = (Efficiency ratio*number released)/(number per pound*number recovered). SSP = Social Security Pond, RC = Rock Creek, DL = Drano Lake, LW = Little White Salmon NFH. BNET = barrier net, Reg = regular, Dbl = double, Trp = triple, and Qua = quadruple density treatments.

Year	Treatment	Efficiency Ratio ($/lb)	Number released	Number per lb	Number recovered	Dollars per recovery
1985	SSP Reg	9.28	204575	106	1578	11.35
	RC Reg	9.90	196064	118	1370	12.01
	LW	5.10	186061	87	3673	2.97
1986	SSP Reg	8.76	210771	90	563	36.44
				78		
	RC Reg	7.64	205930	70	370	54.52
	RC Dbl	3.09	70803		15:	54.83
	RC Trp	2.34	105839	73		25.90
	BNET	29.06	207680	232	88	295.61
	LW	5.10	195310	108	797	11.57
1987	DL Reg	8.61	194917	107	1135	13.82
	DL Dbl	3.96	65880	101	326	7.92
	DL Trp	3.15	98005	110	462	6.07
	DL Qua	2.23	121839	105	637	4.06

0.467%) during 1984-1986 were higher than those of upriver bright fall chinook juveniles from Spring Creek NFH released in the lower Yakima River (mean = 0.322%) and Hanford Reach in the Columbia River (mean = 0.263%) during these years, which supports this theory.

It is unfortunate that the hatchery control fish in 1987 contracted IHN and were subsequently destroyed. The comparison of adult returns from the rearing trials in Drano Lake and hatchery controls from the Little White Salmon NFH would have been a comparison of rearing methods without the confounding effects of differences in release sites. The 1987 rearing trials in Drano Lake resulted in higher adult recoveries in all fisheries than previous off-station trials, indicating a possible site effect. Increases in on-site recoveries at Drano Lake are of particular interest, indicating the low on-site recoveries at the other sites may have been due, not only to mortality associated with dam and reservoir passage, but also to ineffective capture methods: on-site returns from the 1987 trials were recovered at the Little White Salmon NFH ladder. However, these differences could have also been due to changes in ocean conditions.

Fish reared in the net pens may have been less susceptible to disease than fish reared in the hatchery. Although the fish transferred to the net pens in 1987 were from the same bank of raceways as the fish in the hatchery which later were destroyed due to IHN, the disease was not detected in fish from the net pens. The reduced densities in the net pens may have been the reason IHN was not detected in these fish. Increased rearing density has been shown to increase stress in juvenile salmonids, which can increase susceptibility to disease (Wedemeyer 1976; Maule et al. 1989; Salonius and Iwama 1993).

Adult recoveries indicate that densities tested in this study did not exceed the maximum under the rearing conditions at the off-station sites. The increased densities in 1986 and 1987 resulted in more adults per rearing space than the regular density treatments, without appreciable differences in growth, smoltification, mortality during rearing, or adult recovery.

Rearing fish at higher densities may be possible, since the densities used in this study were intentionally conservative because of low water-exchange rates and increasing water temperatures during rearing. Other investigators have found an inverse relationship between juvenile salmonid rearing density and adult contribution (Martin and Wertheimer 1989; Banks 1992). The lack of such a relation in our study supports our belief that the densities tested in this study did not exceed the maximum under the conditions observed during rearing.

The maximum practical loading densities for the rearing methods we used are difficult to estimate, as water temperatures and flow rates can be unpredictable and are beyond the control of the fish manager in backwaters and ponds along the Columbia River. We chose to be conservative in choosing the densities in this study, and manifestations of overcrowding in the rearing enclosures were not noted. Higher densities may have been possible, particularly in Drano Lake, as it had colder water than the other off-station sites.

The accelerated growth and smoltification of fed fish reared off-station compared to those reared at the hatcheries was most likely a result of the increased water temperatures at the off-station sites. Reduced densities at the off-station sites may have also been a factor. Rearing fish without supplemental feeding rarely resulted in a net gain in production; fish in these treatments generally displayed stunted growth and delayed physiological development. Zooplankton densities at Rock Creek and Drano Lake were apparently not sufficient for fish growth. The most successful methods were the fed treatments in pens. The barrier net would probably also be a productive method if fish were fed during rearing; this method should not be discounted for future management uses.

In summary, rearing fish off-station produced mixed results. Fish reared without supplemental feeding did poorly; we do not recommend this method on a production scale. Fish reared in net pens fed a full hatchery ration performed well during rearing and resulted in higher adult contributions than fish trucked to release sites one dam and reservoir upstream, although adult contributions were lower than from releases directly at the hatchery two dams and reservoirs downstream.

Based on growth and physiology during rearing and adult contribution, fed fish reared at the highest densities in net pens proved to be the most productive off-station method used in this study. Rearing densities up to 0.053 lb/ft^3 at stocking (75200 fish per pen) were used successfully when fish were fed Abernathy Dry feed at 3-4% body wt/day. This density was only tested at Drano Lake, which had colder water than the other off-station sites. Rearing fish in backwaters and ponds along the Columbia River may be useful as a repository for "thinning releases"; as a low-cost method to hold increased production when egg take exceeds hatchery rearing capacity: or possibly as an addition to traditional hatchery methods outright.

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Appendix 1. Summary of adult recoveries from upriver bright fall chinook salmon reared and released at Rock Creek (RC), Social Security Pond (SSP), Drano Lake (DL), and the Little White Salmon National Fish Hatchery (LW). Fed pen treatments listed include regular (Reg), double (Dbl), triple (Trp) and quadruple (Qua) densities. Bnt denotes the barrier net treatment. On-site recoveries are absolute numbers, all others are expanded.

Release Year	Treat-ment	Number Tagged	Location/ Code	On-site Recovery					Ocean Recovery					In-river Recovery				
				2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
1984	Reg	72027	SSP/H50606	0	0	0	0	0	1	33	12	6	3	11	15	72	17	0
	Reg	79610	RC/H50607	10	1	0	0	0	4	88	80	4	0	14	90	109	15	0
	--	94847	LW/O51337	26	11	51	21	0	1	100	198	61	0	13	54	257	101	5
1985	Reg	99169	SSP/H50702	0	0	0	0	0	10	62	161	38	0	36	185	331	45	2
	Reg	105406	SSP/H50703	0	0	0	0	0	11	46	124	39	1	42	108	300	28	9
	Reg	96145	RC/H50701	3	1	0	0	0	14	43	134	55	6	10	158	282	70	11
	Reg	99919	RC/H50704	2	2	0	1	0	10	36	115	41	3	3	59	268	36	7
	Bnt	59670	RC/H50705	3	2	0	0	0	2	6	48	10	6	0	31	83	28	0
	Bnt	62856	RC/H50706	7	3	1	0	0	1	19	44	13	0	0	90	141	23	4
	--	22393	LW/O51250	0	3	9	12	1	0	38	52	37	0	0	43	73	19	2
		23100	LW/O51251	0	8	20	15	2	10	108	97	40	6	0	27	130	65	10
		21864	LW/O51256	0	3	28	13	7[a]	7	46	77	19	1	3	24	153	62	3
		26499	LW/O51257	2	11	32	23	3	5	73	118	37	0	4	72	144	92	4
	--	20075	LW/O51252	0	218		9	3	5	72	70	22	0	0	46	111	28	5
		21158	LW/O51253	2	9	23	13	0	0	49	65	63	1	0	25	107	53	0
		25467	LW/O51254	0	9	25	17	3	0	79	74	23	1	4	31	128	56	4
		25505	LW/O51255	1	15	28	17	0	4	74	74	54	8	0	16	163	65	8

(Appendix 1 continued.)

Release Year	Treat-ment	Number Tagged	Location/ Code	On-site Recovery					Ocean Recovery					In-river Recovery				
				2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
1986	Reg	50840	SSP/B50312	0	0	0	0	0	0	10	22	13	0	0	31	42	27	0
	Reg	52946	SSP/B50315	0	0	0	0	0	2	2	24	8	3	0	5	35	63	0
	Reg	52387	SSP/B50314	0	0	0	0	0	0	10	26	25	0	1	11	43	32	0
	Reg	54598	SSP/B50313	0	0	0	0	0	0	1	17	19	4	1	4	68	14	0
	Reg	50757	RC/B50308	0	0	0	0	0	0	16	22	7	0	0	15	17	25	0
	Reg	50817	RC/B50309	0	0	1	0	0	3	3	16	11	3	0	4	15	**26**[b]	0
	Reg	51996	RC/B50310	0	0	0	0	0	0	6	11	28	0	0	10	23	26	3
	Reg	52360	RC/B503 11	0	0	0	0	0	0	0	7	8	6	0	9	36	13	0
	Dbl	35427	RC/B50409	0	0	0	0	0	0	4	4	12		0	0	0	9	0
	Dbl	35376	RC/B50408	0	0	0	0	0	0	1	10	9	0	0	0	15	2	0
	Trp	52631	RC/B50215	0	0	1	0	0	**0**	**1**	**7**	**15**	**0**	0	4	18	**14**[c]	0
	Trp	53208	RC/B50214	1	0	0	0	0	**0**	**10**	**16**	**7**	**0**	0	4	14	19	0
	Bnt	51851	RC/B50213	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0
	Bnt	52128	RC/B50212	0	0	0	0	0	0	0	3	2	0	0	0	22	0	0
	Bnt	51851	RC/B50211	0	0	0	0	0	0	0	4	1	0	0	0	14	6	0
	Bnt	51850	RC/B50210	0	0	0	0	0	0	0	3	0	0	0	21	0	0	0
	--	48147	LW/O51810	0	3	9	22	1	0	4	31	33	3	9	12	18	41	0
		48147	LW/O51809	0	2	7	20	1	0	4	22	17	6	0	11	37	20	0
		49443	LW/O51807	0	3	7	15	1	0	5	28	54	3	0	11	44	62	3
		49573	LW/O51808	0	5	12	22	1	5	20	9	35	6	0	16	32	61	4
1987	Reg	47731	DL/BSOlOl	0	2	19	15	0	4	34	51	35	0	0	38	59	14	0
	Reg	49839	DL/B50102	1	3	23	24	0	4	10	58	24	2	4	15	67	8	0
	Reg	49947	DL/B50103	1	2	35	24	0	0	26	65	22	3	0	6	100	24	0
	Reg	47400	DL/B50104	2	2	28	21	0	0	11	84	35	0	10	18	85	17	0

(Appendix 1 continued.)

Release Year	Treat-ment	Number Tagged	Location/ Code	On-site Recovery 2	3	4	5	6	Ocean Recovery 2	3	4	5	6	In-river Recovery 2	3	4	5	6
1987	Dbl	31671	DL/BSOlOS	2	4	23	11	0	3	4	46	21	0	0	3	43	12	0
	Dbl	34209	DL/B50106	1	3	14	6	0	0	8	28	20	0	0	7	56	11	0
	Trp	49720	DL/B50713	0	2	22	12	0	1	27	45	22	0	0	18	60	19	0
	Trp	48285	DL/B50714	1	2	19	19	0	0	17	43	26	2	0	24	62[c]	17	2
	Qua	59682	DL/B50201	0	3	33	16	0	4	35	68	64	0	0	14	97	8	2
	Qua	62157	DL/B50202	1	7	34	24	0	1	14	72	43	0	0	20	62	15	0

[a] Includes 1 age 7 fish.
[b] Includes 1 recovery at Little White Salmon NFH
[c] Includes 1 recovery at Spring Creek NFH

Appendix 2. Adult recovery summaries (expanded number and percent) of upriver bright fall chinook salmon reared and released at Rock Creek (RC), Social Security Pond(SSP), and controls released at the Little White Salmon NFH (LW), including totals for each area of recovery (on-site, ocean, or in-river).

Treat-ment	Location/ Code	Number Released	On-site No.	On-site %	Ocean No.	Ocean %	In-river No.	In-river %	Total No.	Total %
1984										
Reg	SSP/H50606	27	0 11	0	55	0.076	115	0.160	170	0.236
Reg	RC/H50607	7 0		0.014	176	0.221	228	0.286	415	0.521
--	LW/O51337	94847	109	0:115	360	0.380	430	0.453	899	0.948
1985										
Reg	SSP/H50702	99169	0	0	271	0.273	599	0.604	870	0.877
Reg	SSP/H5070	105406	0	0	221	0.210	487	0.462	708	0.672
Reg	RC/H50701	96145	4	0.004	252	0.262	531	0.552	787	0.818
Reg	RC/H50704	99919	5	0.005	205	0.205	373	0.373	583	0.583
Bnt	RC/H50705	59670	5	0.008	72	0.121	142	0.238	219	0.367
Bnt	RC/H50706	62856	11	0.017	77	0.122	258	0.410	346	0.550
--	LW/O51250	22393	25	0.112	127	0.567	137	0.612	289	1.290
--	LW/O51251	23100	45	0.195	261	1.130	2	1.004	538	2.329
--	LW/O51256	21864	51	0.233	150	0.686	245	1.120	446	2.040
--	LW/O51257	26499	71	0.268	233	0.879	316	1.192	620	2.340
--	LW/O51252	20075	32	0.159	169	0.842	190	0.946	391	1.948
--	LW/O51253	21158	47	0.222	178	0.841	185	0.874	410	1.938
--	LW/O51254	25467	54	0.212	177	0.695	221	0.868	452	1.775
--	LW/O51255	25505	61	0.239	214	0.839	252	0.988	527	2.066

(Appendix 2 continued)

Treat-ment	Location/ Code	Number Released	On-site No.	On-site %	Ocean No.	Ocean %	In-river No.	In-river %	Total No.	Total %
1986										
Reg	SSP/B50312	50840	0		45	0.088	100	0.187	145	0.285
Reg	SSP/B50315	52946	0	0	39	0.074	103	0.194	142	0.268
Reg	SSP/B50314	52387	0	0	61	0.116	87	0.166	148	0.282
Reg	SSP/B50313	54598	0	0	41	0.075	87	0.159	128	0.234
Reg	RC/B50308	50757	0	0	45	0.089	57	0.112	102	0.201
Reg	RC/B50309	50817	1		36	0.071	45	0.088	82	0.161
Reg	RC/B50310	51996	0	0.002 0	45	0.086	62	0.119	107	0.206
Reg	RC/B503 11	52360	0	0	21	0.040	58	0.111	79	0.151
Dbl	RC/B50409	35427		0	11	0.031	9	0.025	20	0.056
Dbl	RC/B50408	35376	0	0	20	0.056	17	0.048	37	0.104
Trp	RC/B50215	52631	1	0.002	23	0.044	36	0.068	60	0.114
Trp	RC/B50214	53208	1	0.002	33	0.062	37	0.070	71	0.133
Bnt	RC/B50213	51851	0	0	0	0	12	0.023	12	0.023
Bnt	RC/B50212	52128	0	0	5	0.010	22	0.042	27	0.052
Bnt	RC/B50211	51851	0	0	5	0.010	20	0.038	25	0.048
Bnt	RC/B50210	51850	0	0	3	0.006	21	0.040	24	0.046
--	LW/O51810	48147	35	0.073	71	0.147	80	0.166	186	0.386
--	LW/O51809	48147	30	0.062	49	0.102	68	0.141	147	0.305
--	LW/O51807	49443	26	0.052	90	0.182	120	0.243	236	0.477
--	LW/O51808	49573	40	0.081	75	0.151	113	0.228	228	0.460

(Appendix 2 continued)

Treat-ment	Location/ Code	Number Released	On-site No.	On-site %	Ocean No.	Ocean %	In-river No.	In-river %	Total No.	Total %
1987										
Reg	DL/B50101	47731	36	0.075	124	0.266	111	0.232	271	0.568
Reg	.DL/B50102	49839	51	0.102	98	0.197	94	0.189	243	0.488
Reg	DL/B50103	49947	62	0.124	116	0.232	130	0.260	308	0.617
Reg	DL/B50104	47400	53	0.112	130	0.274	130	0.274	313	0.660
Dbl	DL/B50105	31671	40	0.126	74	0.234	58	0.183	172	0.543
Dbl	DL/B50106	34209	24	0.070	56	0.164	74	0.216	154	0.450
Trp	DL/B50713	49720	36	0.072	95	0.191	97	0.195	228	0.458
Trp	DL/B50714	48285	41	0.085	88	0.182	105	0.217	234	0.485
Qua	DL/B50201	59682	52	0.087	171	0.286	121	0.203	344	0.576
Qua	DL/B50202	62157	66	0.106	130	0.209	97	0.156	293	0.471